Computational Surgery and Dual Training

Marc Garbey • Barbara Lee Bass • Scott Berceli
Christophe Collet • Pietro Cerveri
Editors

Computational Surgery and Dual Training

Computing, Robotics and Imaging

Springer

Editors
Marc Garbey
Department of Computer Science
University of Houston
Houston, TX, USA

Barbara Lee Bass
Department Surgery
The Methodist Hospital Research Institut
Houston, TX, USA

Scott Berceli
Department of Surgery
University of Florida College of Medicine
Gainesville, FL, USA

Christophe Collet
Labo. Sciences de l'Images, de
Université Strasbourg I ENSPS
Illkirch, France

Pietro Cerveri
Biomedical Engineering Department
Politecnico di Milano
Milano, Italy

ISBN 978-1-4614-8647-3 ISBN 978-1-4614-8648-0 (eBook)
DOI 10.1007/978-1-4614-8648-0
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2013953712

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

While a concept in evolution, *Computational Surgery* is a new discipline that focuses on the application of medical imaging, robotics, biological modeling, simulation, and information technology in surgical treatment of patients. The **COSINE** consortium (*computationalsurgery.org*) founded in 2008 aims to produce a new breed of engineers and scientists who can partner with physicians to evolve the next generation of surgical care. This effort, fueled by the urgent need expressed by thought leaders in the medical device industry, seeks to facilitate the rapid evolution toward computer-assisted surgical-based therapies. At a time where the medical budget of advanced countries is the fastest growing sector of the economy, the challenge to improve efficiency while maintaining the quality of care requires new and innovative solutions. As stated in the inaugural 2010 issue of this book, "The future of surgery is intrinsically linked to the future of computational sciences: the medical act will be computer assisted at every single step, from planning to post-surgery recovery and through the surgical procedure itself." The underpinning of the sentiments is even more true today, with this second issue offering a more mature picture of a field that is taking root in a variety of core disciplines. As a collective group focus, research interests encompass but are not limited to the following areas:

- Modeling and simulation to predict surgical outcomes
- Real-time simulation to augment operating room procedures
- Design of new medical devices to meet procedural needs
- Integration of patient-specific data to procedural planning and outcomes
- Multi-scale modeling of surgical disease

In the current issue, we present recent progresses in four complementary fields of computational surgery:

1. Modeling and Simulation of Surgical Procedures
2. Robotic and Image-Guided Surgical Intervention
3. Image Analysis and Visualization for Surgical Planning
4. Information Technology as a Framework for Surgical Decision Making

Among the primary goals of this book is to promote the development of Cyber-Infrastructure in the operating room, with a particular emphasis on computational methods to optimize the integration of procedural technologies, informatics, and human factors to maximize the delivery of surgical care. We are taking a holistic view of the operating room toward an integrated platform that combines simulation, imaging, and robotics into a new framework for surgeons and engineers, requiring new skills and promising interactions. This book provides a strategic view for developing a cross discipline curriculum in computational surgery aimed at two disciplines:

- Computational scientists and engineers motivated to collaborate with surgeons to improve the state of the art.
- Surgeons who are interested in the cutting-edge computational technology innovations that drive medical imaging, robotics, and virtual surgery simulation.

Following the introduction, which offers a roadmap to achieve this goal, the book is organized into five parts that address successively the computer-assisted management of disease and surgery, the role of image processing in diagnostic and/or intervention, the image driven intervention and robotic, the contribution of modeling and simulation to surgery, and finally the training and performance analysis inherent to this new technology. We have made special efforts to include extended review chapters that define the landscape of the medical knowledge required to facilitate the dialog between specialties. Our special thanks go to Brian Butler, Shanda Blackmon, Mark Davies, Min P Kim, Alan B. Lumsden, Bin S Teh from the Methodist Hospital and William W. Lytton from the Downstate Medical Center, who have provided much of the information provided in this contribution. Other chapters address various innovative computational methods and techniques for surgery improvement, some intended to rapidly open the path toward new practices, and others designed to outline critical areas of active research that require additional development prior to integration into everyday life surgical practice.

Part II of this book discusses the computer-assisted management of disease through medical imaging and image analysis. Detailed in the first chapter is a state-of-the-art virtual reality environment dedicated to the comprehensive planning of surgical and interventional therapies. The following chapter describes the application of computer-aided analysis in the planning and delivery of radiotherapy through use of an integrated system that simultaneously images the patient and controls the local delivery of radiation. The final chapter of this section demonstrates the role of modeling and simulation to predict the cosmetic outcome following local surgical treatment of breast carcinoma.

Part III examines approaches aimed at improving the real-time connection between diagnostic imaging and the delivery of care. In this section, we engage the complexity of multivariate data, requiring both efficient modeling to reconstruct complex images and advanced informatics to facilitate the rapid communication of complex datasets. Driving this work is the development of a better and faster tool to guide surgical intervention.

Part IV builds upon automatic image processing and real-time image guidance to drive sophisticated and complex interventions. This part looks at four complementary fields of application: cardiovascular intervention, orthopedic reconstructions, lung cancer resection, and abdominal endoscopy. The commonality between these divergent disciplines is the extensive use of computers and algorithms to obtain the most accurate and efficient minimally invasive procedures. It is a fascinating area of research where medical imaging, innovative processing methods, and advanced robotic devices come together with simulation algorithms to optimize control and maneuverability. The recent introduction of arthroplasty using personalized resection guides is an excellent example of these challenges, where efficient and robust methods are required to extract clinical landmarks from diagnostic images to reduce uncertainty and increase the reliability of the intervention. Similarly, innovative technologies exploiting miniaturized and smart robots are offering opportunities to gain access to the internal body, through access points that can be quite remote from the region of interest, reducing scars, and speeding up postoperative patient recovery.

Part V returns to the fundamental understanding of disease. Through the mathematical modeling of tissue adaptation and repair, therapeutic opportunities to improve outcomes can be identified. Fundamental to this approach is a model that is sufficiently accurate to provide reliable prediction yet robust enough to work on available clinical data. Several applications from cardiovascular intervention to cancer management, from neurologic disease to bone assessment, are reviewed.

Finally, Part VI discusses the fundamental aspect of training in surgery and the use of computational approaches to assess clinical competence. An improved understanding of the integration and implementation of technology in the operating room is critical to optimizing the efficiency procedures.

Our hope in detailing general concepts and reporting specific examples in computational surgery is to both grow field and bring together modeling, computing, robotics, and imaging into optimal surgical platform. Science discovery in modern surgery will benefit from this unique dialogue initiative between a community of surgeons and computational scientists. Finally we would like to thank the Partner University Fund (PUF), the Atlantis program, and the John F. and Carolyn Bookout Distinguished Endowed chair in support of this team project.

Houston, TX, USA — Marc Garbey
Houston, TX, USA — Barbara Lee Bass
Gainesville, FL, USA — Scott Berceli
Illkirch, France — Christophe Collet
Milano, Italy — Pietro Cerveri

Contents

Part I Introduction

1 A Road Map for Computational Surgery: Challenges and Opportunities 3
B.L. Bass and M. Garbey

Part II Computer Assisted Management of Disease and Surgery

2 Plato's CAVE: A Multidimensional, Image-Guided Radiation Therapy Cross Reality Platform with Advanced Surgical Planning, Simulation, and Visualization Techniques Using (Native) DICOM Patient Image Studies 27
E. Brian Butler, Paul E. Sovelius, and Nancy Huynh

3 Stereotactic Body Radiotherapy/Stereotactic Ablative Body Radiotherapy for Lung Cancer 37
Hua Ren, Shanda Blackmon, and Bin S. Teh

4 Computer-Aided Management in Scoliosis Surgery 57
Tran Nguyen Hoang Thi Tho, Truong Quang Dang Khoa, Vo Van Thanh, Lawrence H. Le, and Vo Van Toi

5 Computational Modeling of Breast Conserving Surgery (BCS) Starting from MRI Imaging 67
D. Thanoon, M. Garbey, and B.L. Bass

Part III Image Processing and Diagnostics

6 A Statistical Framework for Biomarker Analysis and HR-MAS 2D Metabolite Identification..... 89
Akram Belghith, Christophe Collet, and Jean-Paul Armspach

7 Hardware and Performance Considerations for Computational Medicine 113
Edgar Gabriel, Rahma Smaoui, Vishwanath Venkatesan, and Shishir Shah

Part IV Image Driven Intervention and Robotic

8 Cardiovascular Imaging, Navigation and Intervention: Hybrid Imaging and Therapeutics 125
Daynene Vykoukal, Ponraj Chinnadurai, and Mark G. Davies

9 Towards Automatic Computer-Aided Planning in Arthroplasty Surgery by Innovative Methods for Processing the Bone Surface Models 149
Pietro Cerveri, Mario Marchente, Norberto Confalonieri, Alfonso Manzotti, and Guido Baroni

10 Robotic Assisted Lobectomy for Lung Cancer 161
Min P. Kim

11 Robot Interaction Control in Medicine and Surgery: Original Results and Open Problems 169
B. Bayle, M. Joinié-Maurin, L. Barbé, J. Gangloff, and M. de Mathelin

12 Control Issues and Possible Solutions in Robotized Flexible Endoscopy 193
Florent Nageotte, Bérengère Bardou, Philippe Zanne, Laurent Ott, and Michel de Mathelin

13 Beating Heart Surgery: Comparison of Two Active Compensation Solutions for Minimally Invasive Coronary Artery Bypass Grafting 203
Julien Gagne, Wael Bachta, Pierre Renaud, Olivier Piccin, Édouard Laroche, and Jacques Gangloff

Part V Modeling, Simulation and Experimental Data

V.1 Cardiovascular

14 Segmentation and Blood Flow Simulations of Patient-Specific Heart Data 213
Dimitris Metaxas, Scott Kulp, Mingchen Gao, Shaoting Zhang, Zhen Qian, and Leon Axel

15 Assessment of Hemodynamics in DeBakey Type III Aortic Dissections for Planning Surgical Interventions and to Understand Post-Treatment Changes 241
Christof Karmonik, Jean Bismuth, Mark G. Davies, Dipan J. Shah, and Alan B. Lumsden

16 Three-Dimensional Numerical Simulation of Plaque Formation in Arteries 257
N. Filipovic, N. Meunier, D. Fotiadis, O. Parodi, and M. Kojic

17 Rule-Based Simulation of Vein Graft Remodeling 265
Minki Hwang, Marc Garbey, Scott A. Berceli, and Roger Tran-Son-Tay

18 Transport in Nanoconfinement and Within Blood Vessel Wall 273
A. Ziemys, N. Filipovic, M. Ferrari, and M. Kojic

V.2 Cancer

19 Some Models for the Prediction of Tumor Growth: General Framework and Applications to Metastases in the Lung 289
Thierry Colin, Angelo Iollo, Damiano Lombardi, Olivier Saut, Françoise Bonichon, and Jean Palussière

20 Quantifying the Role of Anisotropic Invasion in Human Glioblastoma 315
R. Sodt, R. Rockne, M.L. Neal, I. Kalet, and K.R. Swanson

21 A Mathematical Model for Growing Metastases on Oncologists's Service 331
D. Barbolosi, A. Benabdallah, S. Benzekry, J. Ciccolini, C. Faivre, F. Hubert, F. Verga, and B. You

V.3 Epilepsy

22 Neocortical Simulation for Epilepsy Surgery Guidance: Localization and Intervention 339
William W. Lytton, Samuel A. Neymotin, Jason C. Wester, and Diego Contreras

V.4 Bone

23 Calculation of the Discrete Effective Stiffness of Cancellous Bone by Direct Mechanical Simulations 351
Ralf Schneider and Michael M. Resch

Part VI Training and Performance Analysis

24 Robotics as a Tool for Training and Assessment of Surgical Skill 365
Marcia K. O'Malley, Ozkan Celik, Joel C. Huegel, Michael D. Byrne, Jean Bismuth, Brian J. Dunkin, Alvin C. Goh, and Brian J. Miles

25 Workload and Performance Analyses with Haptic and Visually Guided Training in a Dynamic Motor Skill Task 377
Joel C. Huegel and Marcia K. O'Malley

Erratum E-1

Index 389